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In-Situ Instruments and MEMs

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by

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Supporting the NMP goal of more (and cheaper) science

The ISIM Vision

We believe that planetary exploration should be responsive to discovery, opportunity, and serendipity. It is not the purpose of this roadmap to forecast planetary missions, but to identify a path towards inexpensive and timely access to the solar system and provide supporting technology in key areas.

A Planetary Exploration Strategy

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- Provide infrastructure for commonly visited destinations - telecommunication relays, global positioning systems, navigation beacons.
- Provide low-cost delivery systems - sciencecraft designed for delivery of miniature, highly specific payloads for focussed exploration. New, low cost propulsion and navigation systems are enabling, as are simple entry/descent/landing and mobility systems.
- Develop subsystems for instrument autonomy - modular, general purpose microcontrollers, network communications, power generation and management, mobility and sample acquisition systems.
- Demonstrate microinstrument technology - An inventory of sensors and the tools for rapid prototyping and integration. **This is the role of the ISIM IPDT.**

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Guide to the ISIM Roadmap

Vision (Exploration Strategies)

Instruments & MEMS for Sciencecraft:

Microspacecraft
Penetrators & Landers
Solar Sailcraft
Sample Selection & Return
Aerobots, Rovers, & Moles
Atmospheric Probes

Flight Validation

MEMS for Spacecraft Engineering & Health:

Navigation Systems
State-of-Health Networks
Communication
Propulsion

Flight Validation

Instruments for In Situ Science:

Particles & Fields
Gas & Soil Chemistry
Imaging Spectroscopy
Meteorology
Mineralogy
Seismometry

Flight Validation

INSTRUMENTS

Plasma Analyzer (DS-1)
Soil Moisture (DS-2)

MEMS

Calorimeter (DS-1)
Pressure Sensor (DS-2)
Gyroscope (proposed EO-1)
Accelerometers (STRV-2)
RadFET (STRV-2)

Attributes of In Situ Instruments for NMP

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- Miniaturization
  - Small instruments
  - Spacecraft subsystems (state-of-health, navigation,...)
- New Functionality
  - New measurements for space science
  - Networks and constellations
  - Validation technologies
- Instrument Autonomy
  - Wireless, mobile, self-powered instruments
  - Compatibility with extreme environments
  - On-board smart electronics

Subsystem	Conventional Instruments	Future Instruments
Power	Provided by spacecraft	Batteries & photovoltaics
Data & Telecom	Serial link to spacecraft	Wireless link
Sample handling	Sample received from spacecraft	Instrument, travels to or through sample
Structure	Bolted on to spacecraft	Self-contained, integrated with function
Electronics	Analog and ADC/DAC functions	Analog circuits and embedded processors, data reduction, local networks
Deployment	Shutters, booms, platforms, arms	Full mobility, including micro propulsion

Particles and Fields Validation Plan: DS-1

- Characterization for SEP validation
  - Distinguish sputtered contaminants (esp. Mo) from Xe gas and solar wind constituents
  - Address energy distribution of SEP products
  - Monitor surface deposition
- Validation of next generation plasma spectrometer - best current capability in small package
  - Angle resolved
  - High mass resolving power (~50)
  - Ion and electron energy resolution (~10%) from 1-30 keV
  - Unprecedented, low mass (<<5 kg), power (< 5W), volume
- Demonstration of SEP/Space Physics compatibility

Angle-Resolved Plasma Analyzer

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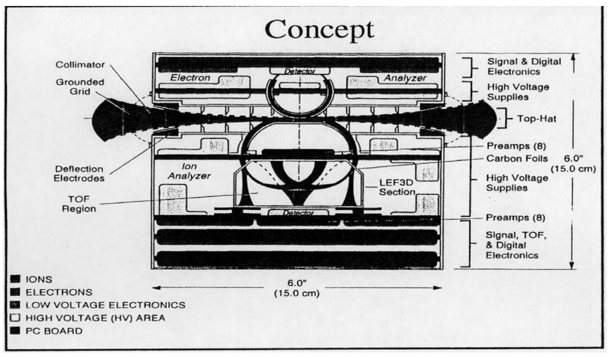


Description

- Electrostatic analyzer coupled to a linear-electric-field reflectron, time-of-flight mass spctrometer
- Approx. 2.2 kg, <10 W
- 2.8 π sr field of view
- 50:1 mass resolving power
- Ion and electron energy resolution from 1-30 keV

Function

- Determination of ion and electron mass and energy distribution for solar wind and planetary environment analysis as well as charaterization of effluent from ion propulsion sources.

Needed by

- Space physics experiments and experimental ion propulsion systems where production of energetic particles via direct emission, sputtering, and interaction with solar wind is an issue.

Assumptions

- TBD

Demonstration

- PEPE instrument on DS-1, coupled with state-of-health monitoring instruments

Evaluation Criteria

- TBD

Attributes of Sciencecraft for NMP

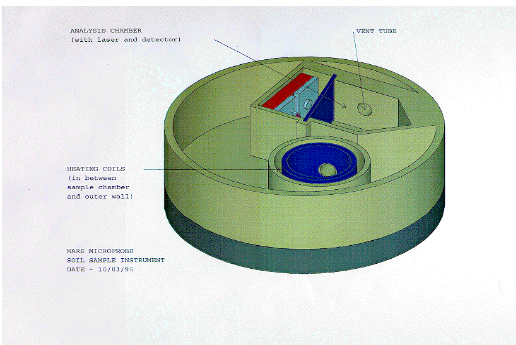
Whereas an autonomous instrument asks very little of the spacecraft, the sciencecraft is based on an opposing philosophy of maximum integration. The sciencecraft, in fact, has more in common with an autonomous instrument than with a conventional spacecraft.

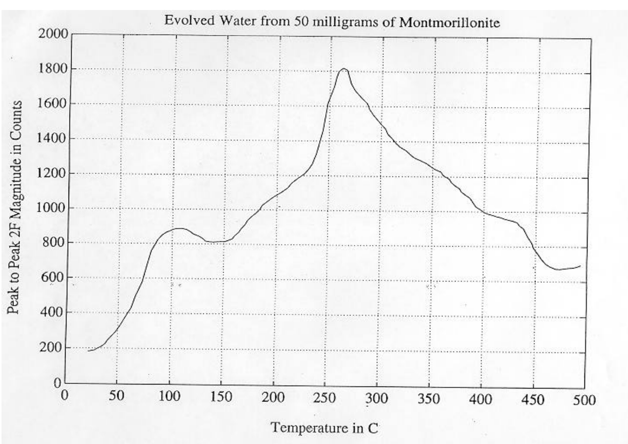
- The sciencecraft only performs functions essential to accomplish the scientific objective
  - Example: Mars Microprobe contains no propulsion or deep space communication
- Instrument and spacecraft share common subsystems
  - Computer and electronics
  - Structure

The Evolved Water Experiment

- Demonstrate passive acquisition of soil sample
  - Ability to preferentially collect subsurface
  - Collection process must not modify sample
  - Ability to seal chamber for analysis
- Demonstrate thermal control of sample
  - Heat sample to boiling/sublimation point to measure evolved vapor
- Demonstrate a miniature spectroscopy system
  - Tunable diode laser spectroscopy to distinguish evolved water quantitatively

Evolved-Water Experiment





Description

- Tunable diode-laser absorption spectrometer
- Controlled Joule heating of sample
- Passive acquisition of soil sample
- Miniature size to fit probe

Function

- Acquires and measures water content of soil sample, demonstrates validity of passive sample acquisition concept.

Needed by

- Evolved volatile analysis for geochemistry, also applicability to atmospheric analysis for meteorology and atmospheric chemistry.

Assumptions

- TBD

Demonstration

- Primary DS-2 instrument

Evaluation Criteria

- TBD

Solar sailing for miniature payloads

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We encourage the development of deployable solar sails to transport very small payloads (0-10 kg) to deep space destinations and back.

- Characteristics of sails and sailcraft
  - Thrust: 9.126 $\mu N/m^2$
  - Achievable Areal Density: $<5\ g/m^2$
  - Overhead (structure, DCS, telecom, navigation, power): 2-5 kg
- Prototypical applications
  - Orbital free flyer (magnetometer & gyro): Sail area $<1\ m^2/kg$
  - Planetary (Mars Microprobe): Sail area $<70\ m^2/kg$
- Advantages over SEP and other low-thrust propulsion methods
  - Appropriate size sails exist today (not true of miniature SEP units)
  - No limit on fuel consumption for, e.g., hover missions
  - Simplicity and safety leads to low cost, high reliability

Attributes of MEMS for NMP

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- NASA needs for MEMS are driven by mission lifecycle costs and requirements for reliability and performance - *not* unit price or manufacturability.
- The principal challenge for NASA is packaging, integration, qualification, and test, with emphasis on compatibility with extreme environments (radiation, temperature, mechanical shock, vacuum, some corrosion).
- To ensure reliability for ten years or more, MEMS designs need to address self test and calibration, graceful degradation, error detection and correction, and redundancy.
- Opportunities exist for utilization of new materials systems (e.g. opto-mechanics with integrated photonics, high temperature materials such as SiC) which might not yet be cost-effective for mass production.

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The Space Environment

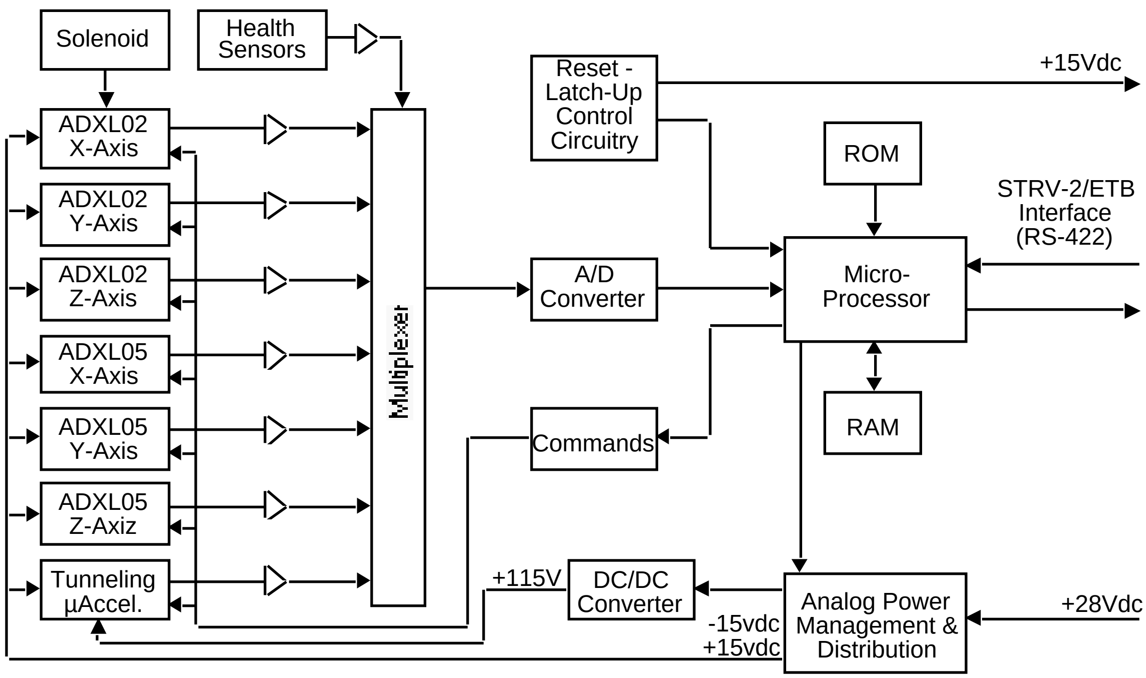
Environmental Parameter	Automotive	STRV-2	Mars Microprobe
Operating Temp.	-40°C to +125°C	-25°C to +40°C	-120°C to 50°C
Thermal Cycling	>1,000	>5,000	<1,000
Relative Humidity	Up to 100%	35% - 60%	N/A
Vibration	15 g sine 10-200 Hz	12 G_{rms} random 20-2000 Hz	18 G_{rms} random 20-2000 Hz
EMI Protection	Up to 200 V/m	Up to 70 V/m	TBD
Shock	N/A	2000 g	< 50,000 g
Radiation	N/A	2×10^5 rads/yr	5×10^3 rads/yr

Microsystems and Packaging for Low-power Electronics (MAPLE)

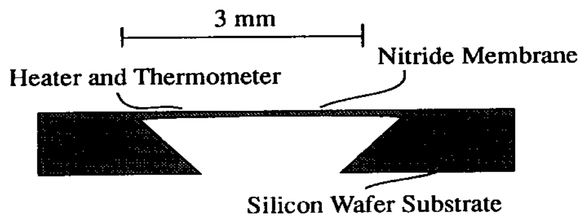
- Payload in Electronic Testbed of the Space Technology Research Vehicle (STRV-2) to be launched in ‘98
  - Satellite will be placed in 410 km x 1,750 km elliptical orbit experiencing high levels of radiation
- Experiment will provide flight experience with:

Technology	Current Experience	MAPLE	Comments
MEMS	ADXL50 in low Earth orbit	ADXL02/05, tunneling µaccel.	Significant reduction in size, weight, and power; establish reasibility of tunneling sensor
FPGAs	Commercial	Rad-hard	Significant improvement in timely hardened system development
2-D Multi-Chip Modules	Hybrid, co-fired ceramic, VCOS	Chip-on-board, patterned overlay	Reduction in size and weight, more advanced capability
Advanced Module Packaging	None	Ball grid array, mini-ball grid	Reflects significant momentum of commercial market
Platstic Component Technology	Limited, with no reliability data	Embedded reliability monitor	Obtain more detailed perform-ance information on packaging

MAPLE Schematic Diagram



MEMS Calorimeter for DS-1



MEMS Calorimeter for Plasma-Surface Interactions

Description

- Bulk silicon MEMS fabrication
- 1 mm x 1 mm element, includes 1mW heater.

Function

- Component of state-of-health package for monitoring changes in thermal and optical equilibrium due to accumulated contamination

Needed by

- Spacecraft, particularly those with sensitive optics or utilizing ion engines or other contamination sources; rovers (for thermal management).

Assumptions

- Not mission critical

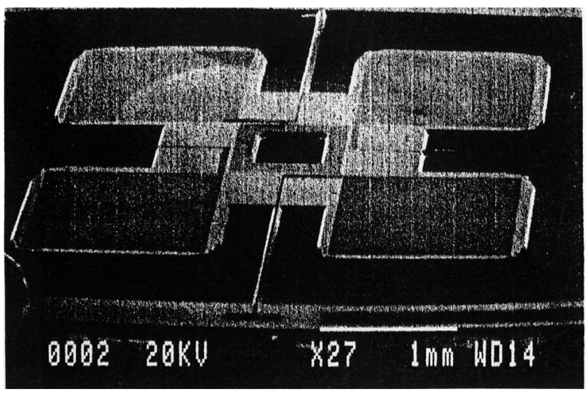
Demonstration

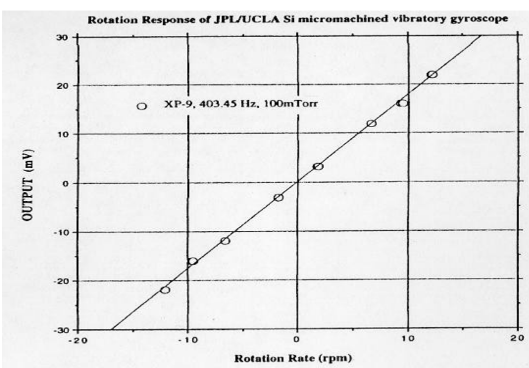
- Accessory to Plasma Analyzer (PEPE) for DS-1. Comparison to conventional calorimeter which is part of NSTAR diagnostic package.

Evaluation Criteria

- TBD

Vibratory Microgyroscope





Description

- Coriolis effect MEMS device
- 3-D fabrication using bulk silicon machining, mechanical assembly with out-of-plane coupling pin.
- 100°/hr bias stability currently; target 1°/hr
- Mass < 1 g, volume < 1 cm^3, and TBD power

Function

- Provides inertial reference

Needed by

- Spacecraft, landers, and rovers for attitude control, navigation, and maneuvering

Assumptions

- TBD

Demonstration

- Second generation proposed for EO-1

Evaluation Criteria

- TBD

IPDT Inter-relationships

- **Instrument Technology and Architecture**
  - ISIM provides MEMS for precision pointing and micro-optics and MEMS fabrication techniques applicable to advanced focal planes
  - IT&A provides focal planes and optics for in situ imaging and spectroscopy.
- **Modular and Multifunctional Structures**
  - ISIM proved sensors and actuators to instrument "gossamer" structures.
  - MAMS products contribute to MEMS packaging (e.g. multifunctional structures) and miniature power systems. MAMS Process Millennia supports MEMS development
- **Autonomy**
  - ISIM provides network of state-of-health sensors and actuators for Autonomy's "Remote Agent" . ISIM also provides gyros and accelerometers for autonomous guidance and navigation.
  - Autonomy's data selection algorithms allow for ISIM instruments to function with low power and bandwidth.
- **Electronics**
  - Electronics provides robust microcontrollers for sensors and networks as well as MEMS packaging.
  - ISIM provides health monitoring and thermal control for electronics
- **Telecommunications**
  - ISIM provides resonators and filters for transponders
  - Telecom provides network and surface-to-orbit communications for sciencecraft, autonomous instruments, and wireless sensors